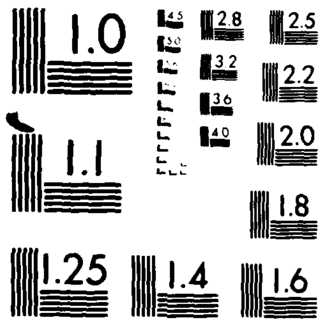
AD-A098 949 ELECTRONIC SYSTEMS DIV HANSCOM AFB MA F/G 4/2
WINDSOUNDING FEASIBILITY DEMONSTRATION.(U)
DEC 80 J F MORRISSEY
UNCLASSIFIED ESD-TR-81-121 NL

END
DATE
FILMED
6 81
DTIC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

ESD-TR-81-121

11

WINDSOUNDING FEASIBILITY DEMONSTRATION

James F. Morrissey
Environmental Surveillance Systems Directorate
Weather Systems Engineering and Test Division
Hanscom Air Force Base, MA 01731

31 December 1980

Prepared for

DEPUTY FOR SURVEILLANCE AND CONTROL SYSTEMS
ELECTRONIC SYSTEMS DIVISION
HANSCOM AIR FORCE BASE, MA 01731

LEGAL NOTICE

OTHER NOTICES

REVIEW AND APPROVAL

This technical report has been reviewed and is apprc.ed for publication.

James F. Morrissey

JAMES F. MORRISSEY, GS-12
Project Engineer
Environmental Surveillance Systems
Directorate

FOR THE COMMANDER

Stanley A Chrest

STANLEY A. CHREST, GS-13
Chief
Weather Systems Eng. & Test Div.
Environmental Surveillance Systems
Directorate

ELECTRONIC SYSTEMS DIVISION

AIR FORCE SYSTEMS COMMAND

HANSCOM AFB, MA

01731

TECHNICAL REPORT

WINDSOUNDING FEASIBILITY DEMONSTRATION

31 DECEMBER 1980

OCR-2

WEATHER SYSTEMS ENGINEERING AND TEST DIVISION

ENVIRONMENTAL SURVEILLANCE SYSTEMS DIRECTORATE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ESD-TR-81-121	2. GOVT ACCESSION NO.: AD-A098 949
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Windsounding Feasibility Demonstration	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): James F. Morrissey	8. CONTRACT OR GRANT NUMBER(s): Hq. USAF PMD No. R-X9045(3)/64708F
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Deputy for Surveillance and Control Systems, Electronic Systems Division, Hanscom Air Force Base, MA 01731	10. 64708F, 642093/Task 01
11. CONTROLLING OFFICE NAME AND ADDRESS: Deputy for Surveillance and Control Systems(OCR), Electronic Systems Division, Hanscom Air Force Base, MA 01731	12. REPORT DATE: 31 December 1980
	13. NUMBER OF PAGES: 40
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Meteorological Sounding Systems
Sond
Windsonde
Drop Windsonde
Winds
Omega
Omega Navigation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The results of a feasibility demonstration of a system for measuring horizontal winds between the flight level of an aircraft and the earth's surface are described. The system utilizes a dropsonde to provide measurements of pressure, temperature, and humidity, and, in conjunction with the Omega Navigation System, provides real-time measurements of the vertical wind profile.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

1.0 INTRODUCTION - In 1974, MAC ROC 4-74 identified the need for a system for measuring winds between the flight level and the earth's surface on meteorological reconnaissance flights. The operational dropsonde system provides measurements of pressure, temperature and humidity but does not allow for wind measurements. In response to the MAC ROC, an effort was instituted at ESD to develop a new dropsonde system with the added wind-measuring capability. This effort was terminated in 1978 due to lack of funds.

The National Oceanic and Atmospheric Administration (NOAA) through a contract with Tracor Corporation had developed a dropsonde system which performed the basic measurement tasks required. This system, Omega Dropsonde Windfinding System (ODWS), had been developed for an international meteorological measurement experiment. NOAA personnel familiar with the Air Force requirement offered the use of one of their ODWS systems to use in a feasibility study. It was felt that if feasibility could be demonstrated, the developmental cost of a system to the Air Force could be greatly reduced.

In June 1979 ESD was directed (PMD #R-X 9054) to demonstrate to what degree the ODWS could be made to satisfy the Air Force requirement.

2.0 EFFORT - To demonstrate that the ODWS could satisfy the Air Force requirement, several changes were made in the system. These changes were necessitated by the basic differences between the Air Force use and that for which it was developed. NOAA developed the system for use as a data logger (cassette recorders) in a scientific experiment. The system was provided with some real-time output but its purpose was just a quick look capability to determine the reasonableness of the data. The purpose of the work in this report was to show that the system could produce real-time information that satisfied an operational need.

The only hardware changes to the system itself were the addition of 16K of memory and some minor wiring changes. The need to perform flight tests in a C-130 aircraft necessitated the development of a pallet for the system, some minor aircraft wiring changes to allow for system power and operation of the dropsonde ejector, and the installation of an aircraft Omega antenna for system use.

The major changes to the system were software changes. The technique used for computing winds was changed to satisfy the accuracy requirement. An automatic means of accomplishing the post-processing of the meteorological data was provided and included the coding required to transmit these data. Finally, a new format was instituted which included operator interaction at several stages.

Testing of the modified system was performed at both Keesler AFB and at the Eastern Space and Missile Center to determine to what degree the system would satisfy requirements. These tests included comparisons with other measurements; radar, radiosonde, and surface observations.

3.0 SOFTWARE MODIFICATIONS

3.1 Wind Measurement - The on-board processing of Omega phase data to obtain real-time winds was one of the principal new elements in this effort. The Omega network is a VLF navigational aid (NAVAID) system with eight ground stations throughout the world. There are three broadcast frequencies used in the Omega system. The ODWS is designed to use one of these frequencies (13.6 Khz). The use of these NAVAID signals to compute

winds has been accomplished in several ground-based systems, shipboard systems, and a few aircraft systems. In the previous aircraft measurements the NAVAID measurements were recorded on magnetic tape for processing after the flight on a ground-based computer. The data reduction techniques used in these applications were, in general, quite complex, and not suited to the computing capability of the system on the aircraft. The Omega signals used are transmitted in a prescribed format with each of the stations transmitting about one second in each ten-second frame. Consequently, the signals used in the wind computation are not contemporary. This, together with the motion of both the sonde and aircraft, means the propagation path to the aircraft is not constant. Since the signal phase is not measured until it arrives at the aircraft, the changes in phase delay can confound the wind measurement.

The technique selected to compute winds on-board was to use a second-order fit to the phase data from each station used, and combine these, using a covariance matrix weighting technique to compute the winds. The combination of differencing necessitated by the geometric solution and differentiating required for finding velocity, removes any constant and first-order confounding of the data introduced by the path delay. The use of the second-order fit also allows removal of some of the acceleration (second order) term in the path delay. The weighting of the computation according to a covariance matrix based on signal quality optimizes the computation when more than three stations are used. The ODWS, as modified, is capable of utilizing four stations. A more complete description of this technique is given in Appendix A taken from the Tracor final report.

3.2 Meteorological data processing - The second important change in the system was the addition of the capability of the system to process the meteorological data at the termination of the drop. This represents automating the functions previously performed by the operator, a description of which can be found in AWS Regulation 105-25. These tasks include, but are not limited to, the following: determining sea-level pressure, identifying missing or doubtful data, determining significant levels, computing mandatory level data, computing heights of the mandatory and significant levels. A description of the processing performed is given in Appendix B which is taken from the minutes of a Tracor design review.

3.3 Coding - The system is designed to encode the data for transmission as prescribed by Federal Meteorological Handbooks 3 and 4 and the "Temp Drop" format published by the World Meteorological Organization.

3.4 Operator Interface Modification - The operator interface underwent major revision reflecting the change in role of the system from a data logger to a complete data processor. This interface is a carbon copy of what was specified in the previous Air Force full-scale development which was terminated. A brief outline of the interface is as follows:

3.4.1. Pre-drop - Prior to dropping the sonde, the sonde calibration must be read into the system. This is accomplished by a paper tape provided by the sonde manufacturer. The sonde is then preflighted to see that it agrees with the calibration. This part of the system was not modified.

In addition to preflighting the sonde, the operator must select the Omega stations to be used in calculating the winds. In the past, this was done according to the geographical

location of the aircraft with the help of a received signal-strength measurement from each Omega station. Unfortunately, the operators sometimes were unduly influenced by signal strength and had no feedback from the system on the quality of the wind measurement using this selection.

This selection procedure has been changed to allow selection of either three or four stations. The operator still has only the signal strength to base his decision on, but the system then responds by giving a figure of merit. This is a single number (0 - 9) which combines the geometry and signal strength. A sample is shown in figure 1.

```
STN A (SEG B) RNS:   3939 NM  BRNG:  26 DS     QUAL: 90
STN B (SEG C) RNS:   4176 NM  BRNG:  94 DS     QUAL: 88
STN C (SEG D) RNS:   4168 NM  BRNG:  284 DS    QUAL: 85   *
STN D (SEG E) RNS:   1356 NM  BRNG:  327 DS    QUAL: 84   *
STN E (SEG F) RNS:   8385 NM  BRNG:  89 DS     QUAL: 58      B
STN F (SEG G) RNS:   4373 NM  BRNG:  168 DS    QUAL: 91
STN G (SEG H) RNS:   1511 NM  BRNG:  131 DS    QUAL: 88   *
STN H (SEG A) RNS:   6667 NM  BRNG:  334 DS    QUAL: 60
 #HYP  D  C  A  G
BITE STN  - E  FIG MERIT: 9
```

FIGURE 1. STATION SELECTION

Each station's signal quality is given in the last column of figures. To the right of these the asterisks indicate the stations currently being used. The B indicates the system is using that stations time for self check (Bite). At the bottom the HYP DCAG is the operator changing to a four station solution (stations D, C, A, G). The last line indicates the bite will be performed in the station E segment and the Figure of Merit is 9 (the highest).

3.4.2 Drop - During the drop the system provides two types of data. Every ten seconds it provides measured pressure, temperature, and relative humidity, and a calculated pressure based on the time of fall. Then every thirty seconds it provides a calculated value of wind speed and direction and the figure of merit. Figure 2.

144	490	-13.8	15	475	
154	494	-13.4	15	478	
164	498	-12.9	14	482	
174	502	-12.4	16	485	
184	506	-12.3	14	488	
194	510	-11.7	15	492	
104					28 290 8
204	514	-11.3	16	495	
214	518	-10.9	16	499	
224	522	-10.3	16	502	
134					34 279 9
234	526	- 9.8	14	506	
244	530	- 9.5	16	510	
254	533	- 8.6	15	513	
164					34 278 9

FIGURE 2. DATA FORMAT DURING DROP

At the end of the drop the system is programmed to detect the end of drop (lack of signal) and inform the operator. The system does not act on this information until directed by the operator to terminate. The operator can also initiate termination without the system signal. At this time the system then provides finer scale data (every two seconds) starting 24 seconds prior to the termination and ending 10 seconds after termination. The operator is then free to select any of these times. Figure 3 is an example.

```
SND 3 SIG LOSS
 #END 3 1254
PROCESS DROP DATA ?   Y
1230  1008   17.3   53
1232  1008   17.4   53
1234  1010   17.5   52
1236  1010   17.6   52
1238  1012   17.8   52
1240  1013   17.8   52
1242  1014   17.9   52
1244  1015   17.9   52
1246  1016   18.0   52
1248  1017   18.1   52
1250  1018   18.3   54
1252  1020   18.4   55
1254  1020   18.5   54
1256  1021   18.7   55
1258  1023   18.8   56
1260  1023   18.8   56
1262  1023   18.8   56
1264  1023   18.8   56
TIME OF LAST GOOD PTH:   1258
1258  1023   18.8   56
INCLUDE WIND DATA?   Y
END OF DROP AT SEA LEVEL?   Y
USE MEASURED PRESSURE VALUES?   Y
```

FIGURE 3. END OF DROP SEQUENCE

The first line of the figure is the system indicating signal loss; the second line is the operator terminating the drop at 1254. The system then asks if it should process drop data. The operator types in Y (yes) and the next 18 lines are the fine scale data (2 second intervals). At the end, the system asks where to set termination and the operator choses 1258. The machine then asks the operator if it should process the wind data, if the drop ended at sea level, and if it should use the measured pressures in computation.

3.4.3 Post Drop - Having received enough instruction from the operator, the system proceeds with the meteorological work-up. There are three stages of this; identification of wildpoints, determining significant levels, and coding. This last contains other functions such as the computing of the mandatory levels.

3.4.3.1 Wildpoints - The system then identifies wild data points. The criteria are: a reverse in the sense of the pressure change, a pressure change of more than 8 mb in ten seconds, a temperature point more than one degree away from the average of the preceeding and following points, or a humidity value more than 10% RH away from both the preceeding and following points. These wild points are presented to the operator and he is allowed to correct this selection. If no corrections are made, these points are removed from the data base. Figure 4 is an example from a flight.

```
PTH WILD POINTS
TIME PR  TEMP  HM
0014 434 -21.8 27 PTH
0024 439 -21.5 32 PTH
0844 800   7.5 37 TH
0854 806   4.1 72 TH
CHANGES ?  USE 844
MORE ?  USE 854
MORE ?  NO
```

FIGURE 4. WILDPOINT IDENTIFICATION FORMAT

The first two points are the first points of the flight. These are routinely removed to make sure the sensors have stablized. The next two points are associated with an extremely sharp inversion. When asked for changes the operator has instructed the machine to use both the points associated with the inversion.

3.4.3.2 Significant Level Data - The system than procedes to identify significant levels according to the procedure described in Appendix B . These levels are then printed out in the form shown in figure 5 .

```
PTH SIG. LEVELS
TIME   PR          TEMP     HM
0034   444        -21.0     34 FL
0114   474        -17.1     49 SH
0614   691          4.2     27 ST
0774   766          7.7     21 XH
0834   795          8.9     21 ST
0864   812          3.7     89 ST
0954   857          7.3     99 XH
1272   1020        21.1     59 FL
CHANGES?   NO
```

FIGURE 5. P, T, H SIGNIFICANT LEVEL DATA

The unmarked column at the right identifies the type of significant level (ST - significant temperature, XH - max. or min. humidity, FL - first and last level, SH - significant humidity). Once again the operator is permitted to change the selection; in this case none were made. The machine then proceeds to identify wind significant levels and prints these for the operator for editing. Figure 6 shows a printout.

WIND SIG LEVELS			
TIME	PR	WS	WA
0104	471	33	242 FL
0224	519	26	245 SD
0314	557	12	277 SS
0344	570	12	257 SD
0404	596	11	267 SD
1064	912	13	79 SD
1154	957	14	83 FL
CHANGES ?	NO		

FIGURE 6. WIND SIGNIFICANT LEVEL DATA

3.4.3.3 Coded Message - The machine then encodes the message as required, prints out the coded message, and asks if the operator wants it transmitted. A sample of a coded message is given in figure 7.

```
XXAA  67184  99285  70805  08180
99023 21258
00192 19457
85564 06804  05013
70157 04668  33012
50579 14159  24529
88999
77999
XXBB  678    99285  70805  08180
00025 21258
11857 07201
22812 03616
33795 08871
44766 07671
5569[illegible] 04267
66474 17[illegible]58
77444 21161
21212 00
      11957  08[illegible]14
      22912  08013
      33596  26511
      44570  25512
      55557  27512
      66519  24526
      77471  24033
TRANSMIT MESSAGE ?    NO
CH 3 CLEAR
```

FIGURE 7. CODED MESSAGE

4.0 FLIGHT TESTS - There were two series of flight tests performed on the system. The first was a series of three engineering flight tests performed at Keesler AFB, MS. The second series, performed at the Eastern Space and Missile Center (ESMC) FL., was designed to measure the performance of the system as an atmospheric measuring device.

4.1 Keesler Tests - The Keesier tests were performed in the February - March 1980 time period. They were engineering tests of the aircraft modifications as well as the system modifications. The end results were several drops showing the system performed the functional tasks required.

4.2 ESMC Flight Test Description - The ODWS flight tests were conducted at the Eastern Test Range (Cape Canaveral) 15 April through 18 April 1980. Over the four day period, 25 Omega sondes were released from approximately 28.6 N, 80.3 W. Each sonde was tracked from the ground by an FPS-16 radar and from the aircraft by the Tracor ODWS. After each release the aircraft flew one of two patterns; one pattern (designated flight path A) was L-shaped with the 90° turn occurring approximately 10 minutes after launch. The other (designated flight path B) was essentially a straight-away pattern. Because of air space restrictions, all patterns included a 40° - 50° turn immediately after sonde release. The pattern for the first drop on 15 April was path A with a 120° turn in place of the 90° turn.

The Tracor ODWS was operated primarily by Tracor personnel on 15, 16 April and primarily by Air Force personnel on 17, 18 April. Three sondes (Drops 23, 24, and 25) were released by Air Force personnel from approximately 33000 feet. The other 22 sondes were released from approximately 23000 feet. The operators chose to have the Tracor ODWS perform a 3 Omega station wind solution for 19 of the 25 sondes. The operators selected a 4 station solution for the other 6 sondes. Table 1 summarizes the configurations for each drop.

Additional profile information was provided by test range personnel in the form of rawinsonde data from balloon launches made during the flight test. Surface meteorological observations on an hourly basis were also provided by range personnel.

The Omega quality throughout the test period was typical; generally good with small fluctuations in measured signal quality. Reports indicate that no stations were down or transmitting at reduced power levels during the testing period.

DATE	TIME	DROP NO	FLIGHT PATH	OMEGA STATIONS	COMMENTS
15 Apr	1453	1	A	D, C, G	RF Dropout; Station C Erratic
	1529	2	B	D, C, G	
	1649	3	A	D, C, G	
	1750	4	A	D, C, G	No Radar; Drop Aborted
	1835	5	B	D, C, G	No Omega from Sonde, Erratic Pressure
16 Apr	1345	6	A	D, C, G	
	1429	7	B	D, C, G	
	1545	8	A	D, C, G	
	1640	9	A	D, C, A, G	
	1725	10	B	C, B, F, A	
	1840	11	A	D, C, G	Poor Omega from Sonde, Drop Terminated Early
	1923	12	A	D, C, G	No Omega from Sonde
17 Apr	1409	13	A	D, C, G	
	1500	14	B	D, C, G	
	1603	15	A	D, C, A, G	
	1648	16	A	D, C, A, G	No Omega from Sonde
	1740	17	B	D, C, A, G	
	1833	18	A	D, C, G	
	1916	19	A	D, C, G	Bad Temperature
18 Apr	1400	20	A	D, C, A, G	
	1446	21	A	D, C, G	
	1532	22	A	D, C, G	
	1724	23	A	D, C, G	High Altitude Drop
	1818	24	A	D, C, G	High Altitude Drop
	1912	25	A	D, C, G	High Altitude Drop. No Omega from Sonde

TABLE 1. FLIGHT TEST DROP SUMMARY

5.0 TEST RESULTS

5.1 <u>Winds</u> - Of the 25 dropsondes released in the test at ESMC, 18 provided useful wind data. Five sondes failed to retransmit Omega data, one sonde was not acquired by radar, and one sonde had as erratic r.f. signal.

The accuracy of the dropsonde wind was taken to be the difference between the Omega-derived wind and the radar-derived wind. Since the ODWS was programmed to use three minutes of Omega data, the radar winds were computed using three-minute position differences. The vector difference between these two winds was computed each thirty seconds. Each flight was then characterized by the root-mean-sum (RMS) of the magnitude of these vector differences. This method has become common practice in deriving wind errors and consequently useful in comparing with other methods.

The mean value of the RMS errors for the 18 drops considered was 3.7 knots. Table 2 is a matrix of the errors according to two variables (flight path and number of Omega stations used). The table contains only 15 drops, excluding the two high-altitude drops and excluding drop #10 which used a less optimum set of stations. In each category the mean of the vector RMS error is given and the number of drops that it represents.

Flight Path	3 Station	4 Station	Total
A	4.02/8	2.97/3	3.7/11
B	3.9/3	2.7/1	3.5/4
TOTAL	3.95/11	2.9/4	3.66/15

TABLE 2. WIND ERRORS (KNOTS/NUMBER OF DROPS)

The two high-altitude drops yielded errors of 4.9 and 4.4 knots and drop #10 had a 4.0 knot error. The difference between the data for flight path A and flight path B is only one or two tenths of a knot and should not be considered significant. Indeed, when data from all the flights during the 400-700 second period, when the turns were made, were compared, the flight path B errors were higher than the flight path A errors (4.16 vs 3.84). The difference between the 4 station errors and the 3 station errors does appear to be significant and on the order of 1 knot.

The RMS errors for each flight are shown in figure 8 plotted against time of day (Zulu). Again, the errors on those drops using 4 stations appear consistently lower than the rest. The flight at 1400 with the 5.5 knots error was examined and the error is dominated by a few points a little over three minutes into the flight. The remainder of the flight errors were on the order of 3 knots. These high errors might well be caused by an ionospheric disturbance. The other flight with a 5.0 knots error at 1429 on the other hand appears to have errors throughout the flight on this scale. Figure 9 shows wind speed and direction comparison of Omega-derived winds and radar-derived winds for one of the drops.

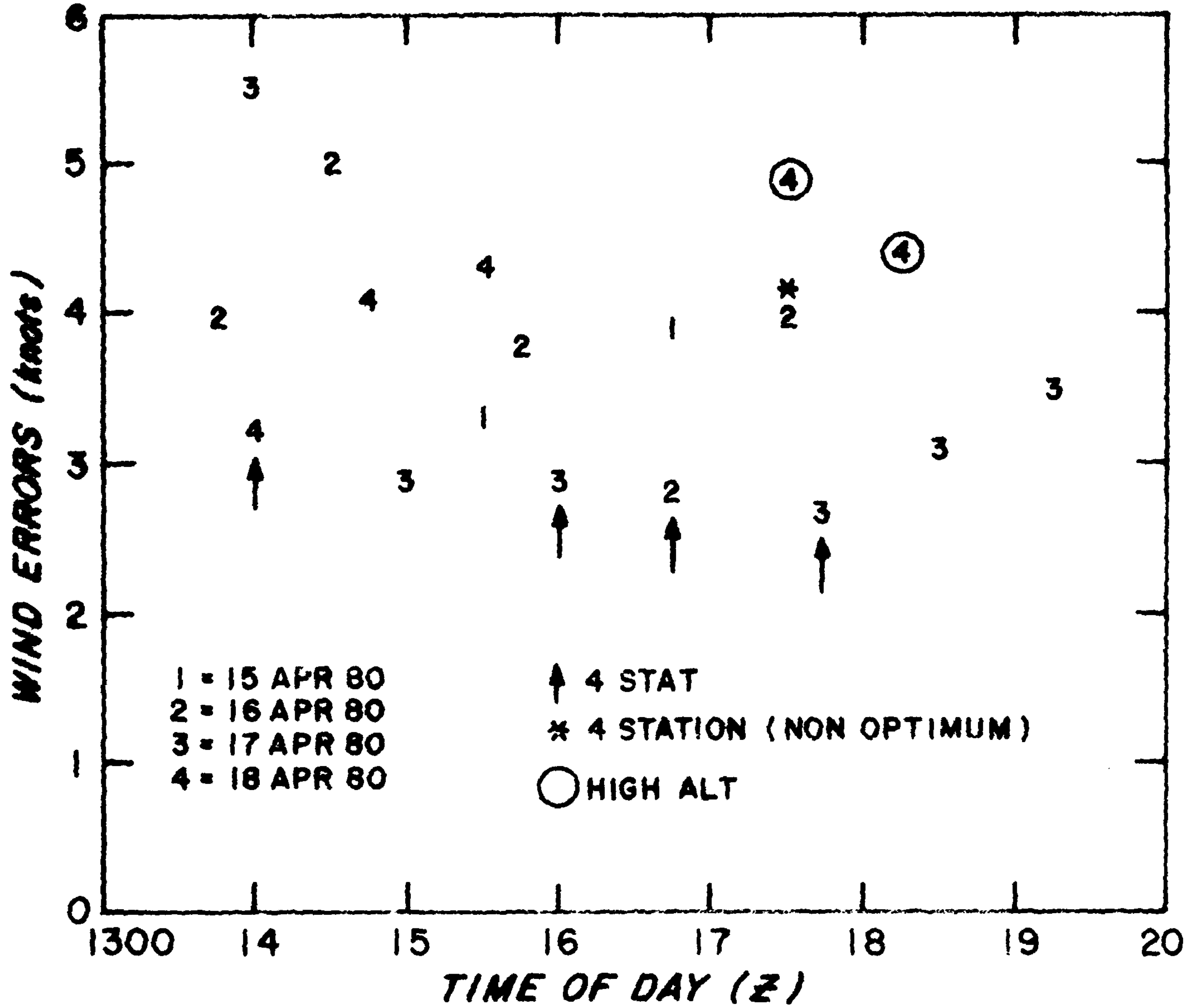


Fig. 8 Wind Errors vs Time of Day

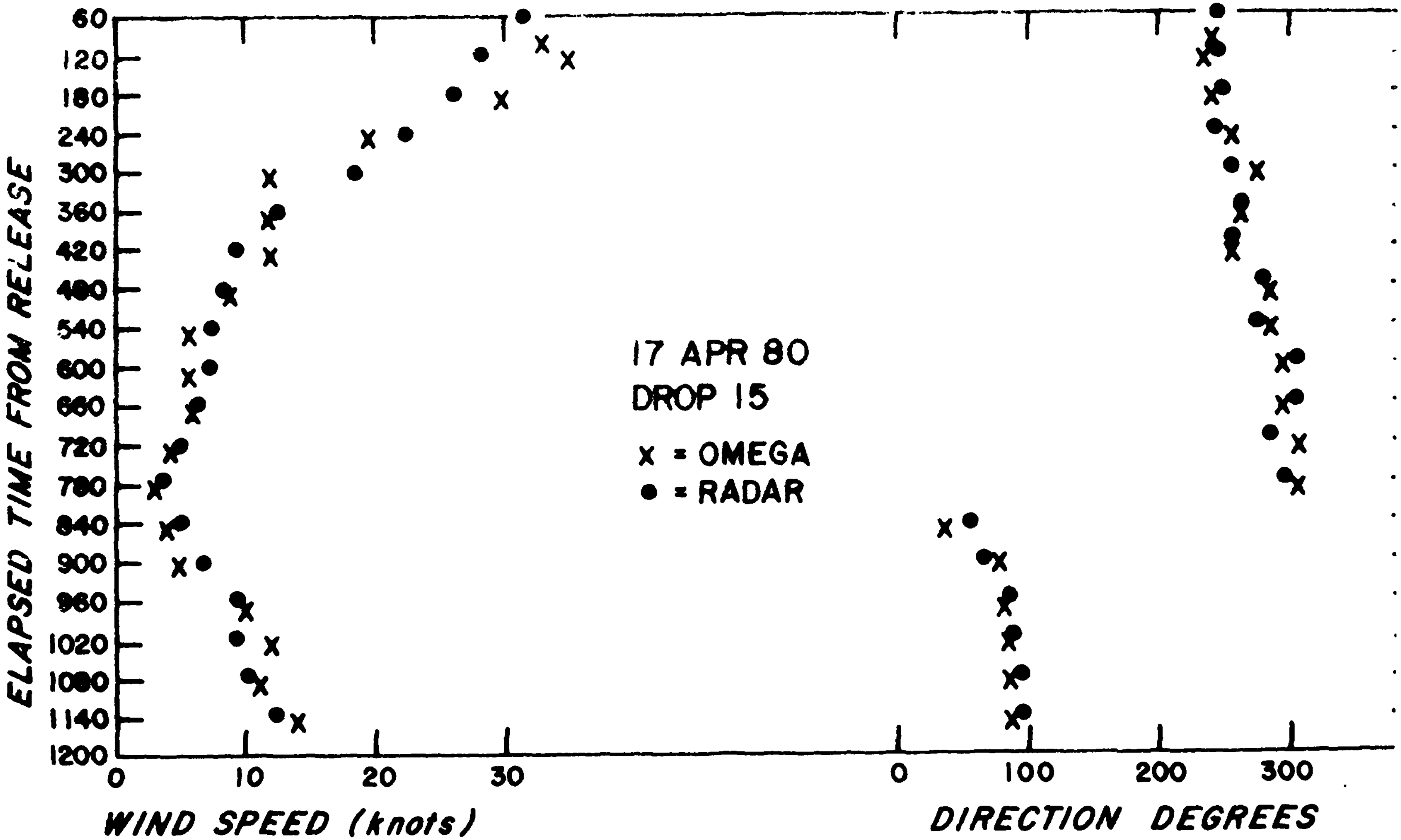


Fig. 9 Omega/ Radar Winds

5.2 Meteorological Data - Surface observations and radiosonde observations were taken in support of this program. In addition, copies of the synoptic radiosonde flights were also provided. It should be noted that this effort did not include any attempt to modify the Omega dropsonde as developed by NOAA and used in their First GARP* Global Experiment (FGGE) experiment. However, the ODWS was modified to use the measured temperature, pressure, and humidity data to provide meteorological data at the mandatory levels.

A comparison of the surface pressure measured by the sonde with that computed by the system and that provided by the surface observation, is given in table 3. The value given as surface observation is extrapolated from hourly observations. The computed surface pressure is obtained from the fact that the height at the beginning and at the end of the drop is known.

*GARP - Global Atmospheric Research Program

DATE	TIME	DROP #	MEASURED	COMPUTED	SURFACE OBS	REMARKS
15 Apr	1453	1	1020	1015	1019.9	Estimated pressures used in computing
	1529	2	1021	1024	1020.0	
	1649	3	1023	1022	1019.4	
	1750	4				Drop aborted, no radar
	1835	5				Erratic pressure cell
16 Apr	1345	6	1023	1023	1022.7	
	1429	7	1021	1023	1023.0	
	1545	8	1024	1024	1023.6	
	1640	9	1054	1026	1023.2	Operator failed to identify EOD
	1725	10	1023	1023	1022.9	
	1840	11	(926)	1015	1022.2	Terminated above Sea Level
	1923	12	(928)	1018	1021.9	Terminated above Sea Level
	2010	—	1020	1021	1021.6	Extra test drop-low altitude
17 Apr	1409	13	1024	1025	1024.0	
	1500	14	1011	1023	1024.0	
	1603	15	1020	1023	1024.0	
	1648	16	1021	1022	1023.8	
	1740	17	1025	1025	1023.5	
	1833	18	1025	1025	1023.2	
	1916	19	1021	1023	1022.7	Erratic temperature
18 Apr	1400	20	1020	1020	1021.0	
	1446	21	1022	1022	1021.1	
	1532	22	1022	1021	1021.3	
	1724	23	1017	1017	1020.9	High Alt Drop
	1818	24	1017	Missing	1020.6	High Alt Drop
	1912	25	1021	1025	1020.1	High Alt Drop

Table 3. SURFACE PRESSURE COMPARISON

The last height computed using the hydrostatic equation and the measured PTH data is then extrapolated to a zero height and a surface pressure. This computed surface pressure is the value transmitted.

Another comparison of the meteorological data can be made by comparison with the radiosonde data at the mandatory levels. For most of the drops the highest mandatory level was 500 mb. Figure 10 shows the height of the 1000, 850, 700, and 500 mb surface as determined on each drop and by the radiosondes. In looking at the graphs, the remarks given for each drop in table 3 should be kept in mind together with the fact the computed surface pressure for drop 24 was missing due to inadvertent editing of that data as a wild point. Figure 11 compares the temperatures at the mandatory levels.

Fourteen of the drops were worked up by either one or two of the drop operators from the 920th WR Group using the ten second data. The comparison of these results is presented in table 4. At the surface pressures are compared while at the other mandatory levels the height of the surface is compared. The surface pressures show exellent agreement. The heights of the mandatory levels snows excellent agreement and consistency up to the 700 mb level. The 500 mb level shows what appears to be a consistently lower height (10 meters) for the machine product.

The significant levels selection by the operators and by the machine were very similar in both number and location. The only significant differences occurred due to the machine precluding selection of one level within 2 data points (20 seconds) of another.

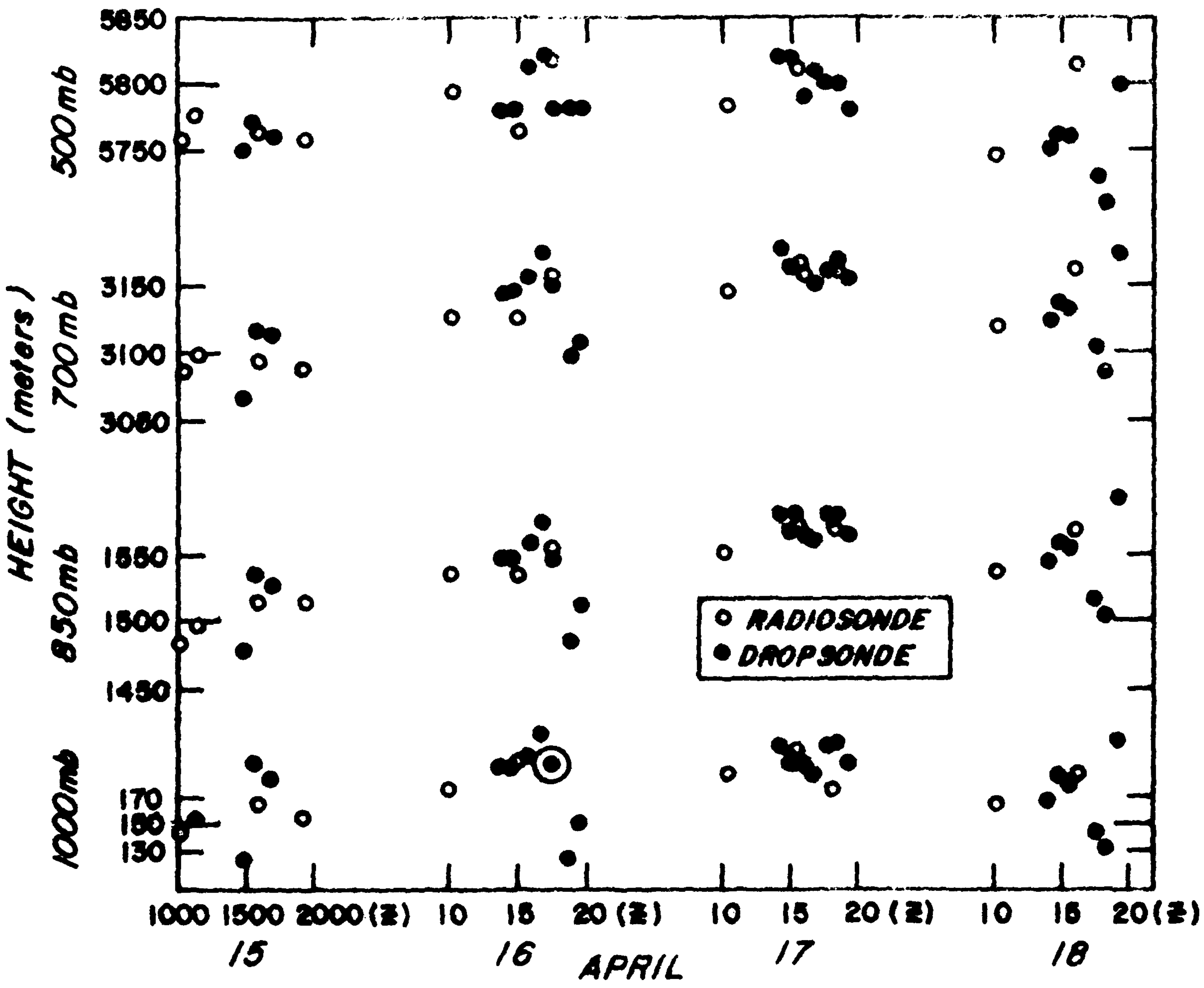


Fig. 10 Height of Mandatory Levels

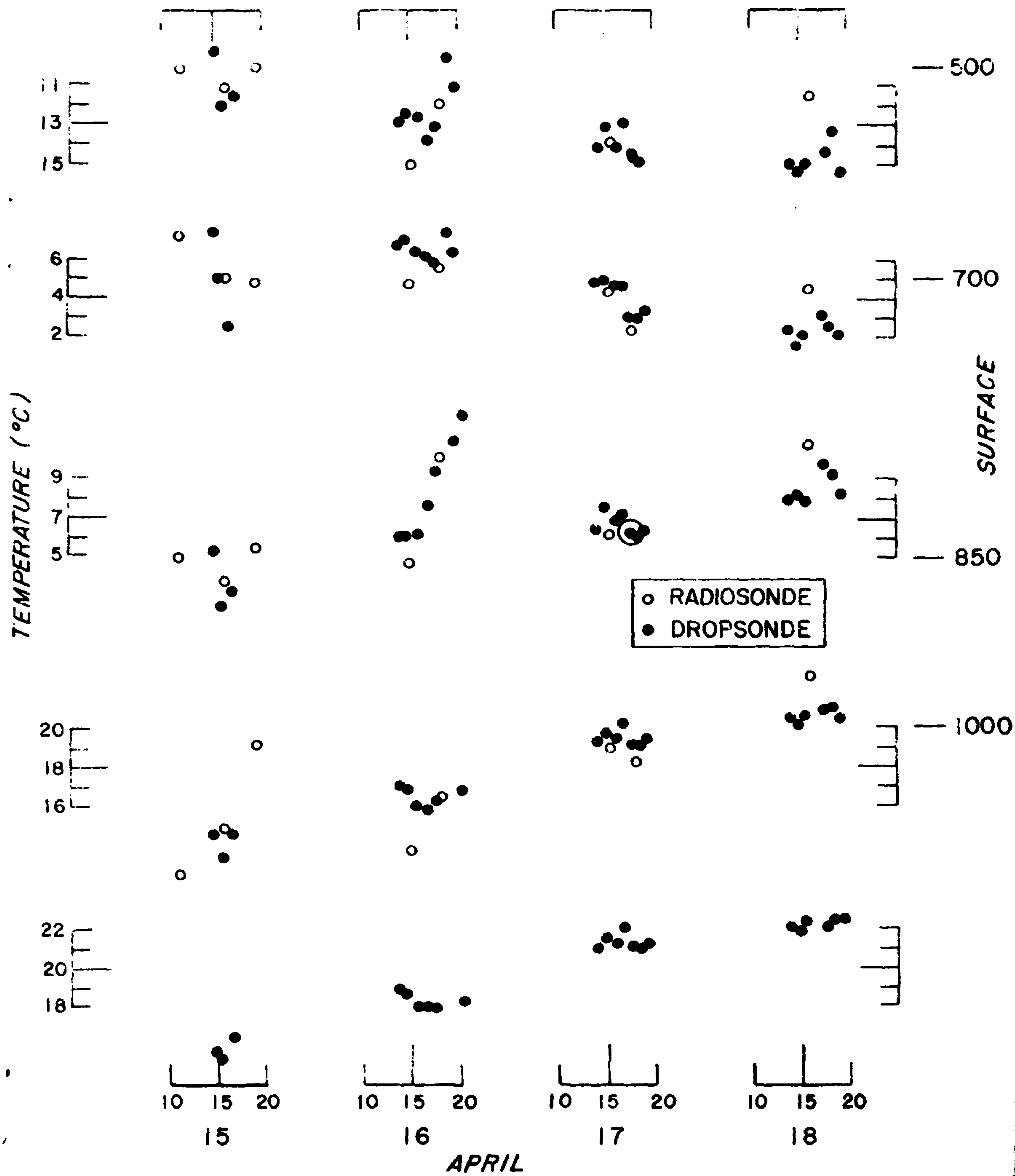


Fig. 11 Temperature of Mandatory Surfaces

Drop #	1	2	6	8	9	13	14	15	16	17	18	19	20
Surface Pressure													
System	015	024	023	024	026	025	023	023	022	025	025	023	020
Operator 1	016	024	023	024	025	024	023	023	021	025	025	023	020
Operator 2		024	023	024	024	025	023	023	023	026	026	023	021
1000 mb height													
System	124	197	191	200	217	208	193	192	186	208	210	192	169
Operator 1	131	198	191	200	212	204	195	198	178	210	211	194	176
Operator 2		198	193	204	202	211	195	193	194	218	219	200	179
850 mb height													
System	1479	1534	1547	1556	1574	1580	1567	1564	1560	1578	1579	1564	154
Operator 1	1483	1535	1547	1553	1565	1572	1567	1568	1550	1578	1579	1563	155
Operator 2		1535	1549	1556	1556	1580	1570	1561	1565	1584	1585	1569	155
700 mb height													
System	3068	3117	3144	3156	3173	3177	3162	3157	3151	3160	3165	3156	312
Operator 1	3067	3118	3147	3153	3167	3166	3165	3161	3151	3171	3171	3156	313
Operator 2		3120	3150	3157	3169	3174	3164	3153	3163	3175	3176	3161	313
500 mb height													
System	5750	5770	5780	5810	5820	5820	5820	5790	5810	5800	5800	5780	575
Operator 1	5770	5780	5810	5810	5820	5820	5820	5810	5810	5810	5810	5800	576
Operator 2		5780	5820	5820	5820	5820	5820	5800	5830	5820	5810	5800	576

Table 4 - Comparison Of Machine And Operator Workups
- Surface pressure (mb - 1000)
- Mandatory level heights (meters)

6.0 DISCUSSION

6.1 Wind Measurement - The accuracy of the wind measurement has been shown, during the test period at ESMC, to be 4.0 knots using three omega stations (Hawaii, North Dakota, and Trinidad) and 3.0 knots using four stations (Hawaii, North Dakota, Trinidad, and Norway). The contractor, in evaluating the wind accuracy, points out that the accuracy improves by a little more than 0.5 knots if the first 400 seconds of data are not included. This effect he attributes to multipath problems in the early stages. A similar problem in the P, T, H data was eliminated with data-editing software routines which he feels could be implemented in the Omega data. The demonstrated accuracy is sufficient to provide useful meteorological data. It is as good or better than that provided by radiosonde flights which provide the bulk of upper air data.

6.2 Post Processing - The post processing of the data to provide significant and mandatory level data was successful. These data compare favorably with the data from surface observations and supporting radiosonde flight data. Figure 10 which compares the heights of the mandatory levels shows excellent agreement for all the regular drops that were terminated at the surface. The drop at 1453 on the 15th used estimated pressures in the workup. The last two drops on the 16th were terminated prior to splash which causes these to be worked down from the aircraft rather than up from the surface. The last three flights of the 18th were high-altitude drops. All of these drops were off by 4 mb or more in their surface pressure, consequently the unrealistic heights of the mandatory surfaces.

Throughout almost all of the drops, comparison of the measured and estimated pressures indicates the estimated pressures are less, by 20 to 30 mb. These estimated pressures are based only on initial pressure and elapsed time and a better estimator should be a simple matter. The effect of this is that if the pressure cell malfunctions and the estimated pressures are used, then the sounding quality is poor. This was the case with the first drop.

The low-level drops that terminated at sea level demonstrated a mean termination pressure error of 0.4 mb and a standard deviation of 1.4 mb. The absolute value of all but two of the errors being less than 2 mb. (Table 3)

The significant level selection does an excellent job with the exception of points where the system precluded selecting a level within two data points of the last level. This part should be changed, probably by either eliminating this restriction altogether, or modifying the way it works.

6.3 Coding

The coded messages produced were found to be generally correct. Several coding errors were found and all of these have since been corrected by software changes. A listing of these changes, taken from the Tracor final report, is given in Appendix C.

6.4 System

The system worked very well during the various tests. There were no major delays of any scheduled tests nor were any tests aborted due to malfunctioning of the ODWS.

Testing on one of the days at ESMC had to be delayed somewhat due to difficulty in loading the program. Similar problems were observed on an engineering flight. Program loading requires about 20 minutes.

The system was successfully operated by Air Force personnel of the 920th WRG. These were drop operators who had previous experience with the ODWS as used in FGGE. Even though they were very high quality personnel, the fact they were able to do this without a formal training program does demonstrate a suitability for Air Force use.

6.5 Dropsondes

The dropsondes used in these tests were the sondes used by NOAA in FGGE. The success ratio for measuring winds was 18 of 24 (excluding unit aborted for no radar). This ratio (.75) is far below the value required (.9) in the previous windsounding specification. While twenty four drops is not a large number, the data from FGGE indicated about .7 for a ratio and this involved a few thousand drops.

The dropsonde sensors appeared to work reasonably well. Of those drops that were terminated at the surface, the mean of absolute difference between the dropsonde-measured surface pressure and that measured on the ground was 2.2 mb. If the one drop with a 13 mb difference is excluded, the mean drops to 2.0 mb. This error is subject to some termination error since the dropsonde pressure is given in whole mb. The temperature measurements appear to agree well with those of the radiosonde and the lack of any bias in the height of the mandatory levels would indicate agreement with the radiosonde measurements.

7.0 CONCLUSIONS

The tests clearly demonstrated the feasibility of satisfying Air Force requirements. The wind accuracy was 4.0 knots using 3 Omega stations and 3.0 knots using a 4 Omega station solution. The system automatically performs the post flight functions needed to prepare a standard dropsonde message (including wind). The system as tested is palletized and could be switched among aircraft that are suitably modified. No effort has been expended to determine how the system could be maintained since it was not directed. It is felt any reasonable maintenance concept would dictate some redesign, i.e., - a ruggedized computer, removal of unnecessary digital cassette recorders, changing program loading. The dropsonde has a success ratio of .75 (probably less) and could use product improvement to improve this to the .9 desired.

James F. Morrissey

JAMES F. MORRISSEY
Project Engineer
Environmental Surveillance Systems
Directorate

APPENDIX A

OMEGA WINDFINDING

The windfinding process consists of three separate segments: initialization, phase data collection, wind computation. The initialization segment runs once per launch. It records the Omega stations to be used in windfinding, initializes all buffers and tables for the sonde and initializes the partial differentials of phase with respect to latitude and longtitude for the selected stations. This initialization is based on the ODW system values of latitude and longitude at launch time.

The phase data collection segment runs continuously for the duration of the drop. As a phase value is received for each of the selected stations, a relative lane count is combined with it and it is inserted in the corresponding 19-place circular buffer, replacing the oldest value in the buffer. The lane count is derived from the lane count of the previous phase reading for the station and the difference in phase between the previous reading and the current one. The relative lane count for each station is arbitrarily initialized to zero at launch.

The wind computation segment runs every 30 seconds starting roughly 200 seconds after launch. The process may be broken down into several steps.

Step 1: Computation of Phase Rates:
In turn each station's set of 19 phase values is approximated by a 2nd order curve using the least squares criterion.

Mathematically, if $\phi = C_0 + C_1 t + C_2 t^2$

then

$$\frac{\partial}{\partial C_j} \sum_i \left[\phi(t_i) - \phi_i\right]^2 = 0 \text{ for } j = 0, 1, 2$$

or, solving for C_j

$$\begin{bmatrix} C_0 \\ C_1 \\ C_2 \end{bmatrix} = \begin{bmatrix} 1 & \sum t_i & \sum t_i^2 \\ \sum t_i & \sum t_i^2 & \sum t_i^3 \\ \sum t_i^2 & \sum t_i^3 & \sum t_i^4 \end{bmatrix}^{-1} \cdot \begin{bmatrix} \sum \phi_i \\ \sum \phi_i t_i \\ \sum \phi_i t_i^2 \end{bmatrix}$$

Phase rates are computed by evaluating the derivative at time t_m, the midpoint of the set of data for the master station

$$\frac{\partial}{\partial t}\Big|_{t_m} = C_1 + 2C_2 t_m$$

STEP 2: Formation of a covariance matrix $\bar{\Sigma}$ from the variance estimates σ_i for each slave and the variance estimate σ_m for the master station

$$\bar{\Sigma} = [\sigma_{ij}] \text{ where } \sigma_{ij} = \begin{cases} \sigma_m + \sigma_i & \text{for } i = j \\ \sigma_m & \text{for } i \neq j \end{cases}$$

The variance estimate σ is computed by

$$\sigma = \sum \left[\phi_i - \phi(t_i)\right]^2/18$$

where ϕ is the curve resulting from the least squares fit.

STEP 3: Formation of Hyperbolic Phase Rates:
The phase rates are differenced (master-slave$_i$) to form the hyperbolic phase rates $\dot{p}$.

STEP 4: Formation of Hyperbolic Partials.
The partials are differenced (master-slave$_i$) to form hyperbolic partials F.

STEP 5: Computation of the Wind Solution:

$$\begin{bmatrix} U \\ V \end{bmatrix} = (F^T \cdot \bar{\Sigma}^{-1} F)^{-1} \cdot F^T \cdot \bar{\Sigma}^{-1} \cdot \dot{p}$$

STEP 6: Update of Sonde Position and Partials.

STEP 7: ~~Conversion to (Speed, Direction)~~ and Output.

The matrix solution indicated in Step 5 is described in the literature by Ranjit Passi. See, for instance, "Wind Determination Using Omega Signals", Journal of Applied Meteorology, Volume 13, December 1974.

APPENDIX B

DOCUMENTATION FOR FORTRAN POST-PROCESSING PROGRAM

1. INITIALIZATION

The data are read into 4 parallel arrays, one each for pressure, temperature and humidity, and one containing a 16-bit flag word for each PTH triplet. The flag bits are to signify the following:

16 -- Value held over-humidity
15 — temperature
14 -- pressure
8 — Point Missing — Duplicate Pressure
7 — Significant level - Humidity
6 — Temperature
5 — First and Last Levels
4 —
3 — Missing Humidity
2 — Temperature
1 — Pressure

Only Bits 14 - 16 may be set as the data are read into the arrays. Those flags signal values which are computed on the basis of held-over values of preceding points because the current value falls beyond the current threshold.

The first valid set of data at the top of the drop is found by comparing sequential values of PTH and the index for this set is identified as init.

2. WILD POINTS, DUPLICATE PRESSURES, AND EXTREME VALUES

Consecutive values of pressure and temperature are compared to detect jumps large enough to represent erratic data. The limits used are 8 MB for pressure and 3 degrees for temperature. Strata of repeated pressure values are found and all data are flagged as missing. Temperature and humidity wild points which differ significantly (by one degree or ten percent RH) from both preceding and following points are flagged, and humidity is flagged as missing for all levels at which the temperature is less than or equal to -40 degrees celsius. Tallies are made of the numbers of wild temperature points and pressure jumps found and if their density exceeds certain criteria -- more than 5 bad points with no intervening sequence of 3 good points — significant levels are set to mark the top and bottom of each stratum of erratic data.

Simultaneously, records of the maximum and minimum values encountered for temperature and humidity are maintained and the lowest level of missing humidity is noted. The last level of good data is labeled 'last' and this level and all the extremes found are flagged as significant. The number of significant levels chosen by this part of the program is greater then, or equal to, 2; there could be as many as 6 significant levels exclusive of those marking strata of missing temperature.

3 STRATA OF MISSING HUMIDITY

Fifty millibar thick strata of missing humidity are noted and marked with significant levels at base and top. These strata will usually be determined by temperatures below -40 degrees.

4. SIGNIFICANT LEVELS FOR TEMPERATURE

The objective in selecting the significant levels is to generate a piecewise-linear approximation to the temperature LN(Pressure) data plot which is within 1 degree (2 degrees above 300 MB) of the data at all points.

The procedure follows the following steps:

(A) Calculate the rate of change between significant levels already chosen.

(B) Find the point in the stratum between the two levels for which the deviation from the interpolation line is maximum.

(C) If the deviation is less than 1 degree, proceed to the next stratum and repeat A-C. If not, set a significant level at the point of maximum deviation and, using the old base and this new level, repeat A-C. Continue in this manner until no point in the stratum being examined deviates by as much as 1 degree from the line of interpolation, and then proceed to the next stratum.

5. TROPOPAUSE SEARCH

If launch was above 500 MB, starting at the surface an upward search is made for the first stratum (determined by significant levels) in which the lapse rate is less than 2 degrees/KM, if the lapse rate does not exceed 2 degrees/KM for 2 KM. Above the base of this stratum, a tentative tropopause is designated at this base level. The search is continued to find the highest level fitting this description below 500MB, or the lowest such level above 500MB. After a first tropopause is found, a 1KM stratum having a lapse rate greater than 3 and lying above the first tropopause must be located before the search for the second tropopause is begun. Only two tropopauses are allowed.

6. SIGNIFICANT LEVELS OF HUMIDITY

Significant levels are determined at points at which the humidity value deviates by more than 10% RH from a line of interpolation determined by the previously selected significant levels. The process is the same as that for temperature. No new significant level will be set if it is 2 points or less from a previously set level.

7. REPORT SIGNIFICANT LEVELS AND ALLOW EDITING

8. SIGNIFICANT LEVELS FOR WIND

Wind data are read into 4 parallel arrays, one for pressure, one each for wind speed and direction, and one for flags. Wind speed is converted to knots. The bits in the flags signify the following:

8 — Primary Maximum
9 — Terminating Maximum
6 — Secondary Maximum
5 — Top and Bottom
4 — Significant Level

The initial good values for wind parameters are found by comparing the wind speed entered at launch with the first 2 wind speeds recorded. (Wind reports too close to EOD -- within 1.5 minutes — will have been discarded so the last wind report is good.) The process for determining significant levels for wind is identical to that used for finding temperature significant levels. The limits used are 10 knots for speed and 10 degrees for direction. Winds with speeds under 10 knots are not considered.

9. WIND MAXIMA

The list of significant levels for winds is searched from the top down to the 500 MB level. The maximum wind over 60 knots encountered and the greatest two winds which qualify as secondary maxima (greater than 60 knots, above 500 MB., and exceeding by 20 knots the adjacent minima) are stored. Two candidates for secondary maximum are stored because the primary maximum could also qualify as a secondary maximum.

10. WIND SHEAR

The wind shear between the maximum wind and the winds at 3000 ft above and below maximum is calculated via the law of cosines.

11. REPORT WIND LEVELS AND ALLOW EDITING

12. COMPUTER HEIGHTS AND SCALE

Using the hydrostatic equation. the heights of the significant levels are computed. If the last set of data does not coincide with zero height (within 25 meters), the error in height (difference from zero) is distributed linearly with respect to the natural log of the pressure. The correction to the heights is:

ERROR * (LN(PA) - LN(PB))/(LN(PS) - LN(PF))

Where PA is pressure at the bottom of the stratum
PB is pressure at the top of the stratum
PS is surface or last pressure
PF is pressure at the first level of good data

13. WORKUP COMPUTATIONS

(A) Interpolate temperature, wind speed and direction for the mandatory levels, and dew point depression for all levels.

(B) Compute marsden square number of launch position

14. ENCODING

APPENDIX I

The following is a collection of specific procedures related to the post-processing subsystem.

GEOPOTENTIAL HEIGHT

The geopotential height of a point is the work required to raise a 1 KG. mass from sea level to the point. The change in geopotential height from level 21 to level 22 (given constant lapse rate) may be approximated by the hydrostatic equation:

DELTA Z = Z2 - Z1 - 29.29 * MVT * LN(P1/P2)

WHERE
MVT is Mean Virtual Temperature (VT1 + VT2)/2 in kelvin
P1 is pressure (in millibars) at height Z1
P2 is pressure (in millibars) at height Z2

VIRTUAL TEMPERATURE

At a given temperature and pressure moist air is less dense than dry air and so in the ideal gas equation (PV = NRT) the gas constant R for moist air differs from that for dry air. The virtual temperature of air is the actual temperature modified to compensate for the water vapor content. That is, the virtual temperature of a packet is the temperature that packet would have if it consisted of dry air at the same pressure and density. Thus, when virtual temperatures are substituted, the gas constant for dry air can be used in all gas equation computations, regardless of the water vapor content of the air. The virtual temperature of moist air is always greater than the actual temperature.

VIRTUAL TEMPERATURE IS APPROXIMATED BY:

VT = T * (1 + (0.3794 * H * SATVP / P)

VT is virtual temperature in kelvin
T is actual temperature in kelvin
H is the % relative humidity / 100
SATVP is the saturation vapor pressure (millibars)
P is the actual pressure in millibars

DEWPOINT DEPRESSION / SATURATION VAPOR PRESSURE

The dewpoint temperature is the temperature to which air must be cooled at a constant pressure in order for it to be saturated with respect to a plane surface of water.

The dewpoint depression is the difference between the actual temperature and the dewpoint temperature.

Vapor pressure is the pressure of the water vapor contained in the air.

Saturation vapor pressure is the pressure of the water vapor when the air is in equilibrium with a plane surface of pure water. That is, rate of evaporation = rate of condensation.

(1) RH = 100 * VP/SATVP
(2) SATVP - 6.1078 * 10 ** (7.63*EX)
(3) EX = T/(241.9 + T)
(4) DT = 241.9 * Log (VP/6.1078) / (7.63*Log(VP/6.1078))
(5) D = T - DT

WHERE
RH is % relative humidity
VP is the vapor pressure of the air (MB.)
SATVP is the saturation vapor pressure at P and T (MB)
P is the actual pressure (millibars)
T is the actual temperature (centigrade)
DT is the dewpoint temperature (centigrade)
D is the dewpoint depression (centigrade)

To determine the dewpoint depression, first find SATVP using equation (2), then determine the actual vapor pressure using (1), find the dewpoint using (4), and finally compute the dewpoint depression using (5).

Equations (2) and (3) are also used to compute the virtual temperature for use in the hydrostatic equation.

MARSDEN SQUARE COMPUTATION

The following algorithm computes the quadrant and the marsden square number from the latitude and longitude. It assumes:

LATDIR is either north or south
LNGDIR is either east or west
LAT is between 0 and 90, inclusive
LNG is between 0 and 180, inclusive

If LAT = 90 then LAT - 89
If LNG = 180 then LNG - 179

CASE (LATDIR, LNGDIR) OF
(north, east): Quadrant - 1, WLNG - 36 - INT (LNG/10)
(south, east): Quadrant - 3, WLNG - 36 - INT (LNG/10)
(south, west): Quadrant - 5, WLNG - INT (LNG/10)
(north, west): Quadrant - 7, WLNG - INT (LNG/10)

CASE QUADRANT OF
3,5: Marsden - 36*INT(LAT/10) + WLNG +299
1,7: If LAT 80
Then Marsden - 36*INT(LAT/10) + WLNG
else Marsden - WLNG + 900

If Quadrant = 5 or Quadrant = 7
then Marsden = Marsden + 1

APPENDIX C

CODING ERROR LISTING

Several coding problems were discovered during the flight test. All but one were associated with encoding the final message and most of these were minor formatting problems (all have been corrected).

1. For Dry ($<$19% RH) strata the dewpoint depression was encoded as 30 instead of 80.

2. The wind shear was encoded as 88 when it should have been 11.

3. Pressure was not rounded properly in the 10166 code group.

4. The wrong wind level was indicated in the XXAA identification line.

5. Wind speed and direction at the 500 mB mandatory level were computed incorrectly for the drops which had a significant wind level at 500 mB.

6. Shear value sof less than 10 kts were coded without a leading zero.

7. Heights were assigned to the 850 mB and 1000 mB mandatory levels on Drop 5 which terminated at 826 mB.

8. Magnetic variations to the West of 0° were not displayed properly although the correct values were used internally.

9. The PTH wild point detection mechanism was determined to be too restrictive near inversions.

10. The 10167 code group was omitted from drops which should have included it.

LIST OF ILLUSTRATIONS

DATE
ILME